LAKE AGASSIZ:

A CHAPTER IN

GLACIAL GEOLOGY.

BY WARREN UPHAM.

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In the last of the geological ages a very cold climate covered the north part of our continent with ice. Every year the snowfall was greater than could be melted away in summer; and its depth gradually increased till its lower portion was changed to compact ice by the pressure of its weight. This pressure also caused the vast sheet of ice to move slowly outward from the region of its greatest thickness toward its margin. Our reasons for believing that there has been such a wonderful glacial period, are abundant and must convince anyone who gives attention to them. The surfaces of the bed-rock at the quarries in this city, (Minneapolis) on Nicollet island and beside the Mississippi farther east, bear fine scratches and markings, called *striæ*, like those which are found beneath the glaciers of the Alps. Only one cause is known which can produce markings like these, and this is the rasping of stones and boulders frozen in the bottom of a moving mass of ice, accumulated upon the land in a solid sheet of great extent and depth. As these *striæ* are found upon the rocky surface of British America and of the northern United States to a southern limit that coincides approximately with the course of the Ohio and Missouri rivers, we must conclude that an ice-sheet has covered these regions.

The superficial material which overlies the bed-rock within this northern glaciated area has everywhere been ploughed up and worked over by the slowly moving ice-sheet, and at its disappearance was left in a deposit of clay, sand, gravel and boulders, mixed in one confused mass, which is called *till.* Except in the valleys, as of the Mississippi at Minneapolis, where streams have assorted these materials and spread them in layers, the till forms the surface of nearly all of Minnesota, its thickness being from 50 to 250 feet. It is the stony and gravelly clay, in which cellars and wells are dug; and it forms a sheet of such great extent and thickness that about half of the counties of western Minnesota contain no exposures of the underlying older rocks.

The thickness of the ice-sheet was so great that its striæ and transported drift are found on the top of Mount Katahdin, of the White Mountains, and the Adirondacks; and over northern Minnesota it was probably of equal depth, or about a mile thick. By the direction in which the boulders have been carried from their original ledges, and by the courses of the glacial markings, we know that the ice moved in general from north to south. In New England its current was southeastward, and the border of the ice-sheet was pushed into the Atlantic to the fishing banks south of Newfoundland and east of Cape Cod. Over Canada and the region of the great lakes, the ice-flow was southwestward. A glacial current moving in this direction has spread upon eastern Minnesota a red till, thus colored by the hematite or anhydrous sesquioxide of iron, contained in the red quartzyte, sandstone and shales of Lake Superior, which were eroded by this ice-sheet. In western Minnesota the ice flowed southward from Lake Winnipeg to Big Stone lake and thence southeast into northern Iowa, spreading a blue till with many boulders of limestone.

Terminal moraines, or hills, knolls and ridges of drift heaped at the border of the ice-sheet, are found stretching in

a remarkably curved and looped course across Wisconsin, Minnesota, Iowa and Dakota. The line of this formation in Minnesota reaches from Stillwater and St. Paul northwest to the vicinity of St. Cloud and to the Leaf hills, this part being at the limit of the ice-current which came from Lake Superior; then from the Leaf hills south by Glenwood, Lake Minnetonka, and Albert Lea, into Iowa to the vicinity of Des Moines, this part being pushed out at the east side of an extensive lobe of the ice-sheet, whose central current went south and south-east; then on the west side of the same glacial lobe, its terminal moraine has been traced from central Iowa northward by Spirit Lake and Lake Benton to the head of the Coteau des Prairies, twenty miles west of Lake Traverse. This moraine was formed at the margin of the areas that were overspread by the ice of our last severely cold epoch.

At some earlier time of the same great glacial period, the ice-covered area extended much farther south, to northeastern Kansas, into Missouri to St. Louis, and to southern Illinois, Indiana and Ohio. Within this area and entirely surrounded by the ice-sheet, a district about 150 miles long from north to south and 100 miles wide, lying in southwestern Wisconsin and adjoining parts of Illinois, Iowa and southeastern Minnesota, was singularly exempted from glaciation. The picturesque bluffs of rock along the Mississippi from Lake Pepin to La Crosse and southward, often standing out isolated and alone like the ruins of turretted castles, are in this region which has no till and has not been planed and smoothed by the ice-sheet.

The end of the glacial period was brought by the genial influence of a milder climate, when the surface of the ice-sheet was melted faster than it was replenished by the snowfall. Its depth and extent could no longer increase, but were thenceforth gradually diminished. While the ice had been growing deeper and much of the snow that fell each year re-

mained unmelted, its surface was probably as smooth and nearly level as our most uniform and monotonous tracts of prairie; and its vast area was one white expanse, unflecked by pebbles, earth or even dust, excepting close to the border where its progress was stayed by melting and the drift which had been gathered into the ice-mass became exposed on its surface and was carried forward and heaped at its margin.

At the departure of the ice the scene was changed. Its surface upon large areas, reaching probably two hundred or three hundred miles from its edge, was hollowed into basins of drainage and channeled by streams which flowed between walls of ice. The boulders, gravel, sand and clay, mingled in the ice, mostly in its lower portion, were exposed by this melting, so that at length, when only a small thickness of the ice was left, its surface must have been covered by the drift which it had contained.

The portion of North America which was overspread by the ice-sheet, and from which it disappeared in this way, was of great extent, reaching from the north part of the United States to the Arctic ocean and from New England to Dakota and westward in British America to the Pacific. The melting and recession of this ice began at its southern border and slowly proceeded northward. Wherever there was free drainage away from the ice-sheet, a large part of the materials of the drift which had been gathered up into it fell in a comparatively loose, unstratified mass, forming the upper part of the *till* with its moderately undulating surface, and covering the land upon which the ice had lain, whether this was bedrock, a ground-moraine, or till formed in an earlier glacial epoch.

Other parts of the drift held in the ice were washed away by its streams and deposited as *modified drift*, forming layers of gravel, sand and fine silt, in the valleys along which the floods supplied by its melting descended toward the ocean.

The high water of the rivers, like that which now occurs for a few days in the freshets of spring, was then maintained through the entire summer; and this was repeated yearly till the glacial sheet had retreated beyond their lines of watershed. The abundant supply of sediment through this time gradually lifted these floods upon the surface of thick and wide plains, sloping with the valleys.

After the departure of the ice, the supply of both water and sediment was so diminished that the streams could no longer overspread these flood-plains and add to their depth, but were henceforth occupied mainly in slow excavation and removal of these deposits, leaving remnants of them as plains or terraces, sometimes 100 to 200 feet, or more, above their present channel. The conspicuous bluffs of loess bordering the Missouri river were formed in this way. Along the Mississippi the flood-plain of modified drift at Brainerd and St. Cloud has a height of about 60 feet above the river; at Clearwater and Monticello, 70 to 80 feet; at Dayton, 45 feet; and at Minneapolis, 25 to 30 feet above the river at the head of St. Anthony's falls.

This review of the condition of Minnesota during the glacial period prepares us to understand how the glacial *Lake Agassiz* was formed in the basin of the Red river of the North, and of Lake Winnipeg during the final melting and gradual recession of the ice-sheet. It thus belongs to the closing epoch of the ice age, when the continental glacier, subdued by a more temperate climate, was yielding its ground between northwestern Minnesota and Hudson bay. During this retreat free drainage from the melting ice could not take place, because the descent of the land is northward. As soon as the border of the ice had receded beyond the watershed dividing the basin of the Minnesota from that of the Red River, it is evident that a lake, fed by the glacial melting, stood at the foot of the ice-fields, and extended north-

ward as they withdrew along the valley of the Red river to Lake Winnipeg, filling this valley and its branches to the height of the lowest point over which an outlet could be found. Until the ice barrier was melted upon the area now crossed by the Nelson river, thereby draining this glacial lake, its outlet was along the present course of the Minnesota river. At first its overflow was upon the nearly level, gently undulating surface of the drift, about eleven hundred feet above the sea, at the west side of Traverse and Big Stone counties; but in process of time this cut a channel here one hundred and twenty-five to one hundred and fifty feet deep, and from one to two miles wide, in which lie Traverse and Big Stone lakes, respectively nine hundred and seventy and nine hundred and sixty-two feet above the sea. From this outlet the Red River valley, thirty to fifty miles wide, stretches three hundred and fifteen miles north to Lake Winnipeg, which is seven hundred and ten feet above the sea. Along this entire distance there is a very uniform, continuous descent of a little less than one foot per mile. The drift contained in the ice-sheet upon this area, and the silt gathered by its glacial rivers, were here deposited in a lake, shallow near its mouth, but becoming gradually deeper northward. Beyond our national boundary this lake covered a large area, varying from one hundred to two hundred miles in breadth at and west of Lake Winnipeg; and its total length appears to have been at least six hundred miles. Because of its relation to the retreating continental ice-sheet, this lake has been named in memory of Professor Louis Agassiz, the first prominent advocate of the theory that the drift was produced by land-ice.

Under the direction of Professor Winchell, the state geologist, it was a part of my work last Summer to trace the course, and determine the height, of the shore line of this

ancient lake. This was done in July and August, the only months of the past season which had sufficiently dry weather for entirely satisfactory progress in such exploration. Horace V. Winchell was my efficient assistant as rodman in the work of leveling, by which the height of the upper beach was ascertained along its whole extent examined. This was about 175 miles, following the course of the old shore, extending from Lake Traverse to the north side of Maple lake, twenty miles east of Crookston. The distance that it includes from south to north is one hundred and forty-two miles.

BEACHES OF LAKE AGASSIZ.

The Upper or Herman Beach. Along nearly the whole of this distance there exists a remarkable deposit of beach gravel and sand, forming a continuous, smoothly rounded ridge, such as is found along any part of the shores of the ocean or of our great lakes where the land sinks in a gently descending slope beneath the water-level. Usually the beach of Lake Agassiz is a ridge three to ten feet above the land next to it on the side that was away from the lake, and ten to twenty feet above the land adjoining it on the side where the lake lay. In breadth this beach-ridge varies from ten to twenty-five or thirty rods. It is thus a broad, wave-like swell with a smooth gracefully rounded surface.

Such being a section across the beach, remember that this ridge extends along the whole distance that we have explored, with only here and there gaps where it has been cut through by streams, ~~at~~ or rare intervals of a quarter or a half mile, or at the longest two or three miles, where the outline of the lake-shore, or the direction of the shore-currents, prevented such accumulation. We find similar interruptions in the beaches of present lakes and on the sea-coast; and like these modern deposits the beach of Lake Agassiz varies considerably in its size, having in any distance of five miles some portions five or ten

feet higher than others, due to the unequal power of waves and currents at these parts of the shore. The moderate slope of the land toward Lake Agassiz was favorable for the formation of a beach-ridge, and it has been clearly traced as one continuous formation along this distance of one hundred and seventy-five miles. In calling it continuous, we mean that whenever it is interrupted it is found a little distance farther along, beginning again at very closely the same height.

The gaps where the beach is not a distinctly traceable ridge-like deposit of gravel and sand, cannot exceed one-twentieth of its whole course. In a few places the lake has undermined its shore, forming a terrace in the till, with no definite beach deposit, the work of the waves having been to erode and carry away rather than to accumulate. In other places, sometimes two or three miles in length, the area where this ancient lake had its margin is a marsh or shaking bog, full of spring-water, and rough with hummocks of grass, which grows luxuriantly but is safe from the hay makers because teams cannot be driven upon these tracts.

Nearly everywhere along the course of this beach of Lake Agassiz the land upon each side is till, or unstratified clay, containing some intermixture of sand and gravel and occasional stones and boulders. The material of the beach-ridge is remarkably in contrast with this adjoining and underlying till, for it includes no clay but consists of stratified sand and gravel, the largest pebbles being usually from two or three to six inches in diameter.

When Lake Agassiz stood at its greatest height and formed this upper beach, its outlet was about eighty-five feet above the present surface of Lake Traverse, or ten hundred and fifty-five feet above the sea. The channel which at this time had been excavated in the drift by its outflow was thirty to forty feet deep along the distance of about fifty miles, where now are Lake Traverse, Brown's valley and Big Stone lake. This

beach is crossed by the Breckenridge line of the St. Paul, Minneapolis and Manitoba railway at a point about one and a half miles northwest from Herman.

The Norcross Beach. Two lower beaches of the same character as to form, size and material, with the highest, were also noted; their course was traced through long distances; and their height was determined by our leveling. At the next epoch after that of the upper or Herman beach, when the lake level was again nearly stationary long enough to form a ridge of gravel and sand upon its shore, the outlet had been eroded about thirty feet deeper than at the time of the upper beach, but was still fifty-five feet above the present Lake Traverse and Brown's valley. The beach of Lake Agassiz when it had this lower level is crossed by the Breckenridge railway line at Norcross, five miles northwest of Herman. This is accordingly named the *Norcross beach.* Its course and height have been determined through an extent of one hundred and fifty miles from Norcross northward to a point twenty-five miles north of Maple lake and ten miles beyond Red Lake Falls.

The Campbell Beach. A third series of beach deposits of similar extent and conspicuous development with the foregoing, was formed when the outlet of Lake Agassiz had been lowered some fifty feet more, completing the excavation of its channel to the present beds of Traverse and Big Stone lakes. The beach of this third stage of Lake Agassiz crosses the township of Campbell in southern Wilkin county from southwest to northeast; and hence it is denominated the *Campbell beach.* The course of this formation through Wilkin and Clay counties has been noted at a few places, and is thus known approximately. Through its next one hundred miles, from the Wild Rice river to the Tamarack river, it has been traced continuously. For forty miles next beyond Red Lake river the old Pembina trail lies most of the way upon this beach. It

has been explored to the north line of Marshall county, sixty miles beyond Maple lake.

Three distinct series of beach-ridges of gravel and sand were thus formed by Lake Agassiz at successive stages of height during its process of deepening the channel by which it outflowed southward.

THE RED RIVER VALLEY.

The central part of the basin of Lake Agassiz, within the limits of Minnesota and Dakota, now drained by the Red river, has an exceedingly flat surface, sloping imperceptibly northward, as also from each side to its central line. The Red river has its course along the axial depression, where it has cut a channel twenty to sixty feet deep. It is bordered by only few and narrow areas of bottom land, instead of which its banks usually rise steeply on one side and by moderate slopes on the other, to the lacustrine plain which thence reaches nearly level ten to twenty-five miles from the river. Its tributaries cross the plain in similar channels, which, as also the Red river, have occasional gullies connected with them, dry through most of the year, varying from a few hundred feet to a mile or more in length. Between the drainage lines, areas often five to fifteen miles wide remain unmarked by any water-courses. The highest portions of these tracts are commonly from two to five feet above the lowest.

This vast plain, twenty-five to fifty miles wide, lying half in Minnesota and half in Dakota, and stretching from Lake Traverse and Breckenridge north to Winnipeg, is the widely famed *Red River Valley.* The material of the lower part of this ancient lake-bed, shown in the banks of the Red river and reaching several miles from it, is fine clayey silt, horizontally stratified; but at its south end, in Traverse county and the south half of Wilkin county, and upon large areas of each side of this plain, it is mainly unstratified boulder-clay,

which differs from the rolling or undulating till of the adjoining region only in having its surface nearly flat. Both these formations are almost impervious to water, which therefore in the rainy season fills their shallow depressions, but none of these are so deep as to form permanent lakes. Even sloughs which continue marshy through the Summer are infrequent, but, where they do occur, cover large areas, usually several miles in extent.

In crossing this almost perfectly level valley on clear days, the higher land at its sides, and the groves along its rivers, are first seen in the distance as if their upper edges were raised a little above the horizon, with a very narrow strip of sky below. The first appearance of the tree-tops thus somewhat resembles that of dense flocks of birds flying very low several miles away. By rising a few feet, as from the ground to a wagon, or by nearer approach, the outlines become clearly defined as a grove, with a mere line of sky beneath it.

Besides this mirage, the traveler is also reminded, in the same manner as at sea, that the earth is round. The surface of the plain is seen only for a distance of three or four miles; houses and grain-stacks have their tops visible first, after which, in approaching, they gradually come into full view; and the highlands, ten or fifteen miles away, forming the side of the valley, apparently lie beyond a wide depression, like a distant high coast.

On all the area drained by the Red river in Minnesota the glacial drift is so thick that no exposures of the underlying rocks have been found. The depth of the drift here is nearly the same as its average throughout the western half of this state, or from one hundred to two hundred and fifty feet. The prominent topographic features of all this region are doubtless due to the form of the underlying rock-surface, upon which the drift is spread in a sheet of somewhat uniform thickness.

Erosion, before the ice-age, had sculptured the rocks which are everywhere buried and concealed under this universal drift-sheet, and had formed the broad nearly level depression of the Red River valley, which is one thousand to eight hundred feet, from south to north, above the sea. Slopes and terraces of these rocks beneath the drift cause the rise eastward from this valley to the lake-sprinkled plateau, thirteen hundred to fifteen hundred feet above the sea, which reaches from Glenwood, Alexandria, and Fergus Falls, to the sources of the Mississippi. For example, though the traveler finds no ledge of rock in going from the Red river at Fargo and Moorhead seventy-five miles east-northeast to Itasca lake, we yet believe that the form of the surface, marked by two remarkable terraces, is due to that of the bed-rock. The flat of the Red River valley extends from Moorhead to about six miles east of Glydon, with a slight ascent of about fifty feet in these fifteen miles. Then the next two or three miles rise two hundred feet to the top of a terrace which reaches from south to north the whole length of the Red River valley in Minnesota, though it is not all the way so distinct nor so high as here. Beyond this ascent the surface is again nearly level, being a sheet of slightly undulating or rolling till, with a rise of perhaps four or five feet per mile through twenty-five miles eastward. Next is a terrace, also reaching a long distance from north to south, which is ascended in three or four miles, rising about three hundred feet, to the White Earth Agency, which thus commands a very extensive western prospect. Thence a more rolling plateau extends, with little change in its average height, thirty miles eastward to Itasca lake.

In like manner the elevation of the Coteau des Prairies in southwestern Minnesota, one thousand five hundred to two thousand feet above the sea, and the terrace-like ascent at the west side of the flat Red River valley in Dakota, lying at a distance of twenty to thirty miles west of the Red river, and

stretching from the south bend of the Sheyenne river north to the British line where it is called Pembina mountain, are undoubtedly due to the contour of the bed-rock, rather than to differences in the thickness of the drift.

The till upon each side of Lake Agassiz has a moderately undulating and rolling surface. Within the area that was covered by this lake it has a much smoother and more even contour, but has been only slightly stratified. The action of its waves gathered from this deposit of till, which was the lake-bed, the gravel and sand of its beaches; and corresponding deposits of stratified clay, derived from the same erosion of the till, sank in the deeper parts of the lake. But these sediments were evidently of small amount, and are not noticeable upon the greater part of this lacustrine area, which consists of a smoothed sheet of till. The position of the thick beds of stratified fine silt and clay in the central depression of the Red River valley, shows that they were not deposited by the waters of Lake Agassiz, which must have spread them more generally over its entire area; but instead appears to prove that they were brought by the rivers which flowed into this hollow and along it northward after the glacial Lake Agassiz had been reduced to its present representative, Lake Winnipeg.

Wells within this area show the character and depth of the drift, but none that we have learned of within the basin of Lake Agassiz in Minnesota are certainly known to penetrate through this formation. The nearest point in our state at which the exact depth of the drift is known is Herman, about a mile outside the upper beach, where the till or stony clay, yellow near the surface but bluish below, reaches to the depth of one hundred and twenty-four feet, beyond which a well was drilled sixty-five feet in rock, mostly mica schist. At Campbell a well two hundred and sixty feet deep went all the way in till, excepting occasional layers of sand and gravel,

mostly thin, but at one place eight feet thick, from one hundred and sixty-five to one hundred and seventy-three feet below the top. At Fargo, in Dakota, the first ninety-five feet were stratified clay; next was a layer of gravel, ten feet; then till, one hundred and fifteen feet; below which the remaining forty-two feet were probably Cretaceous strata, being soft, dark-blue shale, thirty-two feet; coarse sand rock, six feet; and a second shale, four feet, in which the well stopped at a total depth of two hundred and sixty-two feet.* Deep wells farther north in the Red River valley, are at Ada, two hundred and seventeen feet; near Crookston, one hundred and ninety, one hundred and ninety-five, and two hundred and five feet; at Grand Forks, in Dakota, two hundred and sixty-five feet; at South Angus, eighteen miles north of Crookston, two hundred and fifty-three feet; and at St. Vincent, one hundred and sixty-five feet. Perhaps none of these wells, excepting those at Herman and Fargo, reach through the drift; but the two mentioned at Grand Forks and St. Vincent, which yield salty and alkaline water, may go below it, and if so, the stratified gravel and sand in which they stop are of Cretaceous age.

The fame of this valley for its large harvests of No. 1, hard wheat, averaging twenty bushels to the acre, is nearly equalled by the unenviable reputation of the water supplied by its wells. The drift upon this part of the state contains much of the carbonates and sulphates of lime and magnesia, derived from the Cretaceous strata which covered this area and were ploughed up by the ice-sheet, mixed with much drift from the region of granites, gneiss and crystalline schists on the northeast, and redeposited as till. These alkaline ingredients of the soil are often seen in the dry season forming a white or gray efflorescence, resembling frost, sometimes a quarter of an inch thick.

*Report of U. S. Geological Survey of the Territories, 1872, p. 301.

Wheat thrives better where the soil contains a considerable portion of these alkaline salts, so that their presence throughout the Red River valley is one principal cause of its superiority in wheat-raising; and this, grown year after year, gradually takes away these ingredients and prepares the land for other crops. But their effect as dissolved everywhere in wells and streams partly offsets this benefit, and makes the water of all this region objectionably hard, and often in wells and springs noticeably bitter with salt, especially in the northern part of this valley both in Minnesota and Dakota.

These waters, too, more readily than pure water, decompose the wooden curbing, which, being the most convenient and cheapest material, is too commonly used in the wells of this region destitute of stone-quarries. Usually these wells become after a few weeks or months very offensive to taste and smell; the water is discolored, gives off sulphureted hydrogen, and horses and cattle refuse to drink it or are made sick by it. Let such wells be pumped so as to fill them with new water every day, and these offensive qualities are principally removed. Instead of wood, the material for lining wells ought to be stone, iron pipe, or bricks, the last of which are manufactured in many places, and may be made almost anywhere, from the stratified clay along the Red river, of excellent quality and at moderate cost.

Artesian wells have been obtained at many places in this valley. Usually in its southern part, as far northward as Crookston, their water has less alkali in solution than the shallower surface wells. The largest flow yet found is on the Fountain Valley farm, owned by C. H. Brush & Co., situated four miles east of Campbell. This well went fifty-six feet in till to a layer of sand which is known to be ten feet thick and was not penetrated at this depth, making a total of sixty-six feet. The diameter of the pipe is one foot, reduced below to seven inches. A large stream of very clear, cold water is

constantly flowing away from this well, its estimated volume being seven or eight barrels per minute, or about two hundred and fifty gallons. It has been flowing at this rate more than a year. This water is of excellent quality for house and farm use, but is hard and slightly irony, and deposits rusty sediment in the channel of the stream. Its temperature is forty-six degrees Fahrenheit.

The Ada town-well, two hundred and seventeen feet deep, four inches in diameter, supplies a stream which partly fills a one-inch pipe. It was bored last Spring, and has since been running at the rate of one hundred barrels per day. This water is very transparent, and forms no irony sediment. Its cool temperature, forty-seven degrees Fahrenheit, and its purity, being called soft water, nearly equal to rain-water for washing, makes this a very satisfactory investment for the town. Its cost was about five hundred dollars.

Another well nearly like the last in the amount of flow and character of the water, is at E. S. Corser's elevator, at Carman, one mile south of Crookston. Its depth is one hundred and ninety feet.

The deepest well learned of in the Red River valley is at Grand Forks, two hundred and sixty-five feet deep. This has an artesian flow; but, at the time of my visit in last August, its rate of flow, probably because the pipe had become choked with sand and clay, was very small, not amounting to more than two or three barrels in twenty-four hours. This water has a decidedly brackish taste, and is therefore worthless for any ordinary use. The well at St. Vincent, one hundred and sixty-five feet deep, is of the same alkaline character. Both were bored to supply water for locomotives, but cannot be used because of their mineral residue.

It may be that these very deep wells derive their alkaline and salty water from Cretaceous strata; but some shallower artesian wells in this north part of the Red River valley get

quite brackish water from layers of gravel and sand contained in the drift. One of these is on the farm of E. N. Davis, in the south edge of Kittson county, about 30 miles south of the national boundary. This is forty-five feet deep, and was bored in a quarter of a day with an ordinary two-inch auger. Its flow has continued nearly constant through more than a year, at the rate of three pailfuls a minute, or more than three hundred barrels daily. Its temperature is forty-two degrees. Though salty to the taste, it was drank freely by farm-stock through all last winter, with no apparent injury; and it has been used by people as the only water for drinking and cooking through several weeks of drouth. The height to which it will rise is known to be more than twenty-three feet, at which height the flow seemed to be undiminished.

The upward pressure and abundant supply of water in these wells show that the water-bearing layers of stratified drift enclosed in the till are continuous through long distances and descend from a higher level. The veins of soft water found at the depth of about two hundred feet at Ada and Carman probably have their sources upon the high land twenty miles distant eastward.

THE OUTLET OF LAKE AGASSIZ.

The excavation of the remarkable valley occupied by the Minnesota river was first explained in 1868 by Gen. G. K. Warren.* who attributed it to the outflow from this ancient lake that filled the basin of the Red river and Lake Winnipeg. This valley or channel begins at the northern part of Lake Traverse, and first extends southwest to the head of this lake, thence southeast to Mankato, and next north and northeast to the Mississippi at Fort Snelling, its length being about

*Since the above was written, the lamented death of this distinguished soldier and engineer, whose interest in science added much to our knowledge of the geography and geology of the Northwest, occurred August 8, 1882.

two hundred and fifty miles. Its width varies from one to four miles, and its depth is from one hundred to two hundred and twenty-five feet. The country through which it lies, as far as Carver, about twenty-five miles above its junction with the Mississippi, is a nearly level expanse of till, only moderately undulating, with no prominent hills or notable depressions, excepting this deep channel and those formed by its tributary streams. Below Carver it intersects a belt of terminal moraine, composed of hilly till. Its entire course is through a region of unmodified drift, which has no exposures of solid rock upon its surface.

Bluffs in slopes from twenty to forty degrees, and rising one hundred to two hundred feet to the general level of the country, form the sides of this trough-like valley. They have been produced by the washing away of their base, leaving the upper portions to fall down and thus take its steep slopes. The river in deepening its channel has been constantly changing its course, so that its current has been turned alternately against the opposite sides of its valley, at some time undermining every portion of them. In a few places this process is still going forward, but mainly the course of the Minnesota river is in the bottomland. Comparatively little excavation has been done by the present river. As we approach its source it dwindles to a small stream flowing through long lakes, and we finally pass to Lake Traverse, which empties northward; yet along the upper Minnesota and at the divide between this and the Red river, this valley or channel and its enclosing bluffs are as remarkable as along the lower part of the Minnesota river. It is thus clearly shown to have been the outlet of Lake Agassiz, excavated while the melting ice-sheet supplied extraordinary floods, much greater in volume than the combined waters of the Minnesota and Nelson rivers at the present time.

This valley in many places cuts through the sheet of drift,

and reaches the underlying rocks, which have frequent exposures along its entire course below Big Stone lake. This excavation shows that the thickness of the general drift-sheet upon this part of Minnesota averages about one hundred and fifty feet.

Lakes Traverse and Big Stone are from one to one and a half miles wide, mainly occupying the entire area between the bases of the bluffs, which rise about one hundred and twenty-five feet above them. Lake Traverse is fifteen miles long; it is mostly less than ten feet deep, and its greatest depth probably does not reach twenty feet. Big Stone lake is twenty-six miles long, and its greatest depth is reported to be from fifteen to thirty feet. The portion of the channel between these lakes is widely known as Brown's Valley. As we stand upon the bluffs here, looking down on these long and narrow lakes in their trough-like valley, which extends across the five miles between them, where the basins of Hudson bay and the Gulf of Mexico are now divided, we have nearly the picture which was presented when the melting ice-sheet of British America was pouring its floods along this hollow. Then the entire extent of the valley was doubtless filled every Summer by a river which covered all the present areas of flood-plain, in many places occupying as great width as these lakes.

Gen. Warren observes that Lake Traverse is probably due to a partial silting up of the channel since the outflow from the Red River basin ceased, the Minnesota river at the south having brought in sufficient alluvium to form a dam; while Big Stone lake is similarly referred to the sediment brought into the valley just below it by Whetstone river. Twenty-five miles from Big Stone lake, the river enters Lac qui Parle, which extends eight miles, with a width varying from one-half to three-fourths of a mile and a maximum depth of twelve feet. This lake, as Gen. Warren suggests, has been

formed by a barrier of stratified sand and silt which the Lac qui Parle river has thrown across the valley.

THE NORTHERN BARRIER

by which the water of Lake Agassiz was restrained from flowing in the direction of the present drainage, to Hudson bay, is supposed by Gen. Warren to have been an elevation of the land much above its present height northeast of Lake Winnipeg. He thinks this elevation was shared by other northern portions of North America, and that these regions have recently been depressed at least several hundred feet. The depths of the great lakes, and many topographic features of the interior of the continent, besides this channel of lakes Traverse and Big Stone and the Minnesota river, appear to him to support this opinion. Instead of this we believe that the surface of the continent had nearly the same form then as now, and that the continental ice-sheet, resting on the land in a solid mass of great depth, formed the northern shore of Lake Agassiz and was the barrier that prevented its flowing into Hudson bay.

Before adducing the evidence, apparently amounting to positive proof, of this glacial origin of Lake Agassiz, which is drawn from our exploration of its beaches and determination of their height, we ought to mention that Professor Dana's and General Warren's theory of an elevation of the northern part of the continent, during the ice-age or since that time, followed by subsidence to its present height, is opposed and disproved by the general occurrence of sea-beaches and marine shells above the present sea-level all along our northern shores. They show that the ocean in these recent epochs covered more of the land than now in northern latitudes; that is, that the elevation of the land, as compared with the sea-level, was less instead of greater than at present.

More than this, the height at which these recent marine deposits and sea-shells are found, increases from south to north. In New Hampshire and Maine it is from fifty to three hundred feet above our present sea-level; in the St. Lawrence valley about five hundred feet; and on the coast of Labrador, about Hudson bay, and in Greenland, six hundred to fifteen hundred feet. Our proof that the ice-sheet was the northern barrier of Lake Agassiz, also gives us an answer to the question why the sea-level thus rose higher than now toward the north.

The three series of beach-deposits before described, which mark the shores of Lake Agassiz at as many stages of its height, have each been traced, and their altitude determined, through an extent of about one hundred and fifty miles from south to north; and each of them, like the old sea-level, is found to have a gradual ascent northward, as compared with the present level-line, or the surface which a body of water would have now, if confined in this valley. As before stated, these beaches were formed at epochs when the lake-level was nearly stationary for a considerable time, during the excavation of its channel of outlet at Lake Traverse and southward. The height of the mouth of the lake and its outflowing river was at the time of the upper or Herman beach eighty-five feet above Lake Traverse; at the time of the Norcross beach this outlet had been lowered thirty feet; and when the Campbell beach was formed, it was nearly at the present level of Lake Traverse. Our exploration and leveling along the upper beach extended from the north end of Lake Traverse about twenty-five miles eastward to Herman and thence about one hundred and forty miles north to Maple lake. Through this distance it lies from fifteen to thirty miles east of the Red river. The ascent of this beach northward is at the rate of about four-tenths of a foot per mile in its southern portion for about sixty miles, lying in Traverse, Stevens, Grant, Otter Tail, and Wilkin counties. Farther north, through its remaining eighty miles

in Clay, Norman and Polk counties, its rate of ascent is considerably greater, varying from three-fourths of a foot to one and a half feet per mile. In all, the surface of lake Agassiz at this time of its greatest height ascended northward, above a line now level, one hundred and twenty-five feet in these one hundred and forty-two miles, from ten hundred and fifty-five feet, very nearly, above sea in Traverse county, to eleven hundred and eighty feet, very nearly, at the north side of Maple lake, twenty miles east-southeast from Crookston. Through this distance the upper beach clearly marks one continuous shore-line; and the accuracy of our leveling is attested by close agreement with railroad surveys at five widely separated points.

Before Lake Agassiz had fallen below the line of this upper beach in the south half of its explored extent, it had formed a slightly lower parallel beach, three-fourths to one and one-half miles distant, through the northern third of Clay county; and this secondary beach, sometimes double or treble, was noted at several places along the next thirty miles northward. The continuation of this beach at the northwest side of Maple lake was accumulated when Lake Agassiz had fallen at this latitude about fifteen feet below its highest line. Here it is the second of a series of four well-defined beach-ridges, below the upper or first beach, which were formed when the lake had fallen successively about eight, fifteen, thirty, and forty feet from its highest level. Yet all these beaches were accumulated while the lake remained with only very slight depression of level, not sufficient for the formation of any secondary beach-ridge, along its southern part for some seventy-five miles northward from Lake Traverse and Herman.

The Norcross beach has been explored and its height measured through a length of one hundred and fifty miles. In this distance it ascends northward about seventy feet by a nearly uniform slope of a little less than a half foot per

mile. The amount that the surface of Lake Agassiz had fallen at this time from its highest level was thirty feet in Traverse and Grant counties, fifty feet in northern Clay county, and ninety feet northwest of Maple lake. Its fall in this extent of one hundred and fifty miles had been thus sixty feet more at the north than at the south end. Double and multiple ridges occur along the northern half of this distance, and show that the lake-level at the time of formation of the Norcross beach fell five to ten feet northward while it remained without change, or with less change than was required to form additional beach-ridges southward.

The height of the Campbell beach, formed when the outlet had been excavated to the level of Lake Traverse, is known along a distance of one hundred and thirty-five miles, in which its northward ascent was at first fifty feet, and afterward only about twenty-five feet. This continued depression of the lake northward, while it remained with slight or no change southward, is indicated, similarly with the foregoing, by the occurrence of an additional ridge along the northern part of the course of this shore-line. The fall of Lake Agassiz from the upper or Herman beach to the Campbell beach was about eighty feet at the south near Lake Traverse and one hundred and sixty-five feet at the north near Maple lake; and instead of the northward ascent of the upper beach one hundred and twenty-five feet in one hundred and forty-two miles, we find the corresponding ascent of the Campbell beach in nearly the same distance at first fifty feet but reduced later to half this amount.

If the barrier north of Lake Agassiz had been land, its subsidence to give way for drainage northward in its present course would cause the beach deposits of the former lake-shores to have the opposite slope, or a decent, from south to north. These observations are therefore inconsistent with such explanation of the cause of this lake; but they appear

to prove that its northern barrier was the receding continental glacier. All the differences of the once level lines of Lake Agassiz from our present level-line would be produced by the gravitation of the water of the lake toward this ice-sheet. At first this attraction had a large effect upon the lake-level because of the nearness of a great depth of ice on the east in northern Minnesota and northward in British America; but it was gradually diminished to a comparatively small influence when these ice-masses had been melted and the attracting force proceeded from the region far north between Lake Winnipeg and Hudson bay.

In the same way the ocean during the glacial period was drawn toward the ice-sheet, so that northward it stood higher than now, as shown by its recent deposits along our northern coasts, far above the present sea-shore. It appears that the form of the surface of the continent during the ice-age was about the same as it is to-day; but that the sea-level was much changed by the great accumulations of ice, being drawn toward them by gravitation and thus raised higher than now toward the poles, while it was proportionately lowered about the equator.

AREA AND DEPTH OF LAKE AGASSIZ.

The upper beach of Lake Agassiz, as here described from Lake Traverse and Herman north to Maple lake, extends through a prairie region, very favorable for exploration and leveling. Its farther course turns to the east and northeast and lies in a trackless forest, much of which consists of almost impassable tamarack swamps. It is therefore quite impracticable to trace its course exactly through this wilderness; but from the known elevation of Red lake, eleven hundred and forty or eleven hundred and fifty feet, very nearly, above the sea, of the Lake of the Woods, ten hundred and forty-two, and of Rainy lake, about eleven hundred and sev-

enty-five, the outline of Lake Agassiz when it had its greatest height can be mapped approximately.

From the north side of Maple lake it first extends east sixty miles, passing south of Red lake. Next this shore of Lake Agassiz turns northward east of Red lake, beyond which it again runs eastward, crossing the Big Fork of Rainy Lake river, and extends along the south side of Rainy lake, its height above Red and Rainy lakes being probably between fifty and one hundred feet. Thus Lake Agassiz at its time of greatest height reached along our northern boundary beyond the meridians of Minneapolis and St. Paul. Its expanse included no islands, excepting rarely one of small area close to its shore.

When this glacial lake attained its greatest extent, just before it found an outlet into Hudson bay over the melting ice-sheet, its length from south to north was probably greater than the length of Lake Superior; but its area was only half or two-thirds that of Lake Superior, because of its less average width.

At the time of the formation of its highest beach, the depth of Lake Agassiz above the Lake of the Woods was some two hundred feet; above the Red River valley at our northern boundary, four hundred and fifty feet; and above Lake Winnipeg, about six hundred feet.